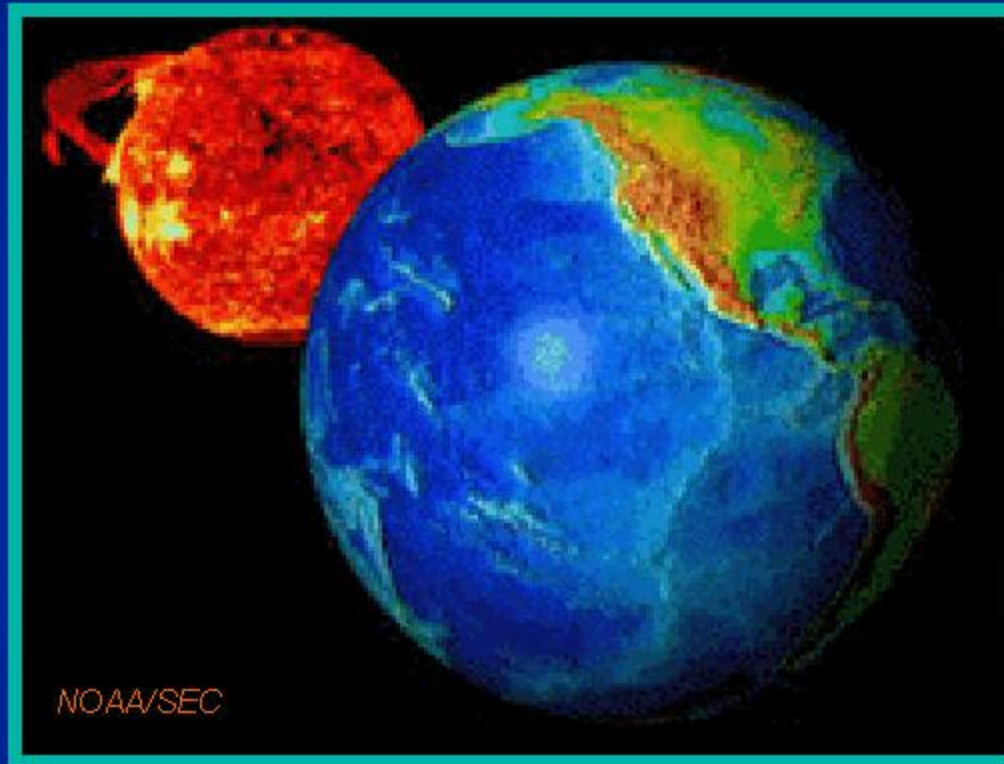




# ***Radiation Environments and Environmental Models***



**Michael Xapsos and Janet Barth**  
**NASA/Goddard Space Flight Center**  
**Flight Electronics Branch/Code 561**



# ***Acknowledgements***

- ◆ **E. G. Stassinopoulos**
  - » **Head, Radiation Physics Office (RPO)**
- ◆ **Ken LaBel**
  - » **Group Leader, Radiation Effects and Analysis (REA)**



# *Outline*

- ◆ **Background - Solar Activity**
- ◆ **Solar Particle Events**
- ◆ **Galactic Cosmic Rays**
- ◆ **Trapped Radiation**
- ◆ **Summary**



# ***Background: Solar Activity***



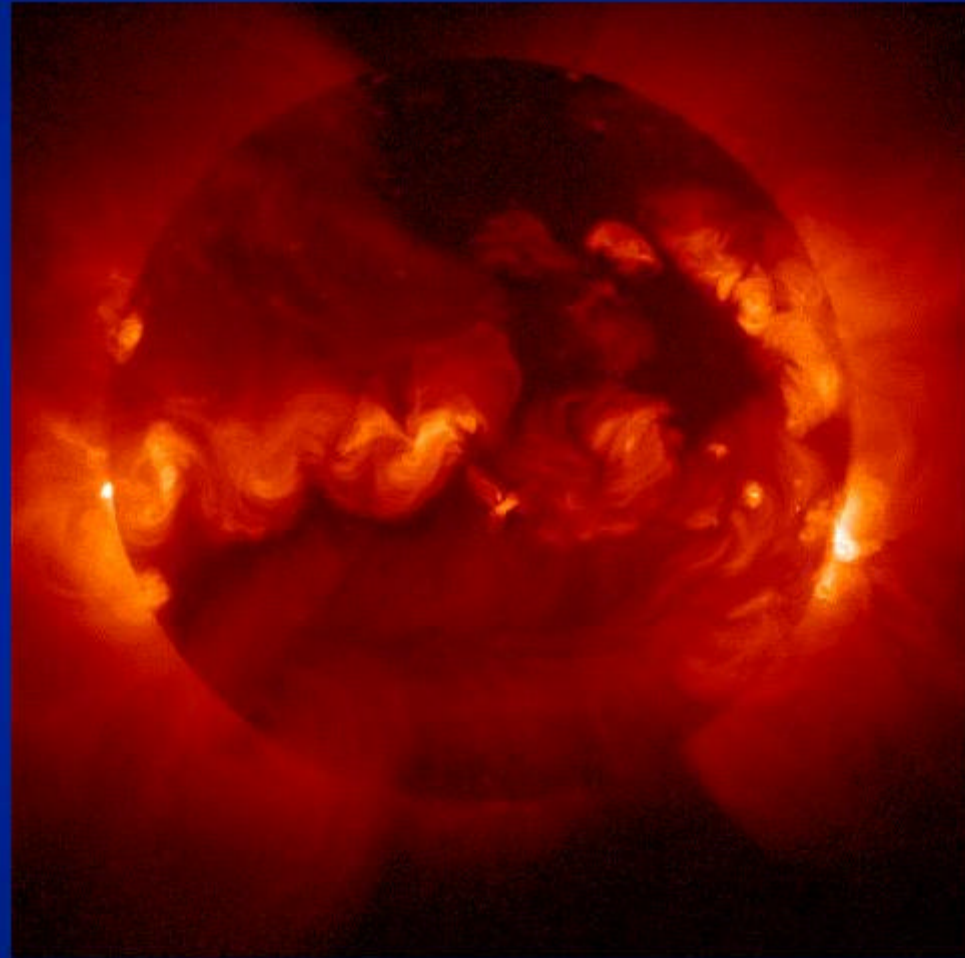
# *The Sun*

- ◆ **Controls space environments**

- » **Source**
- » **Modulator**

- ◆ **Structure**

- » **Photosphere**
- » **Chromosphere**
- » **Corona**

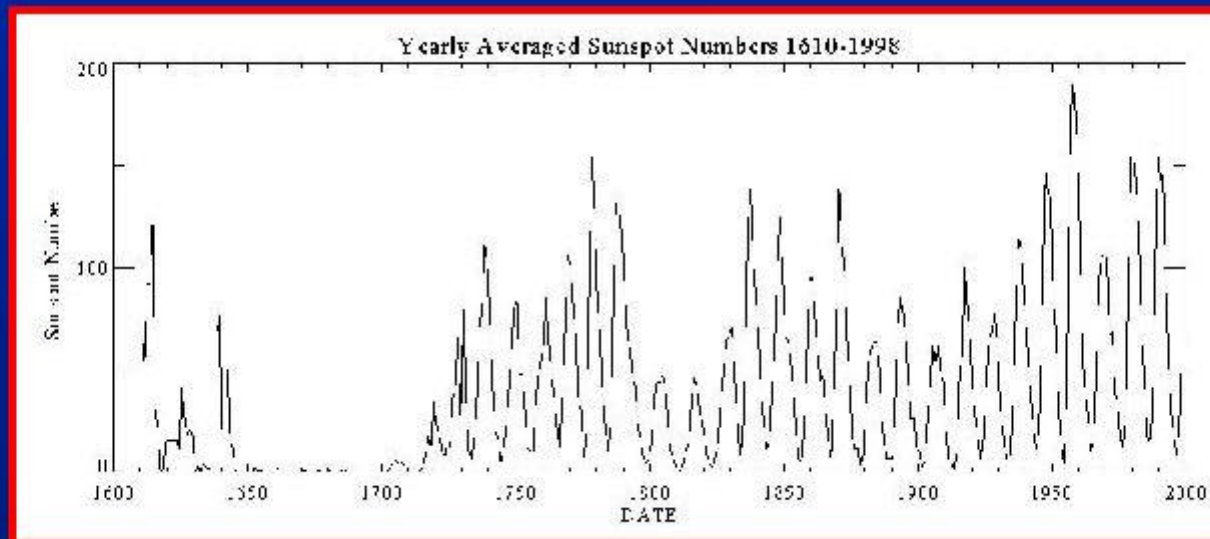
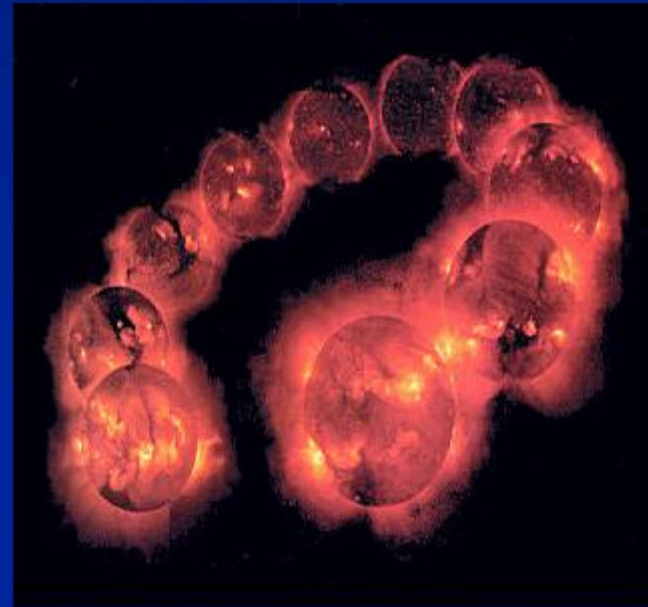


*Yohkoh/SXT*



# *The Solar Activity Cycle*

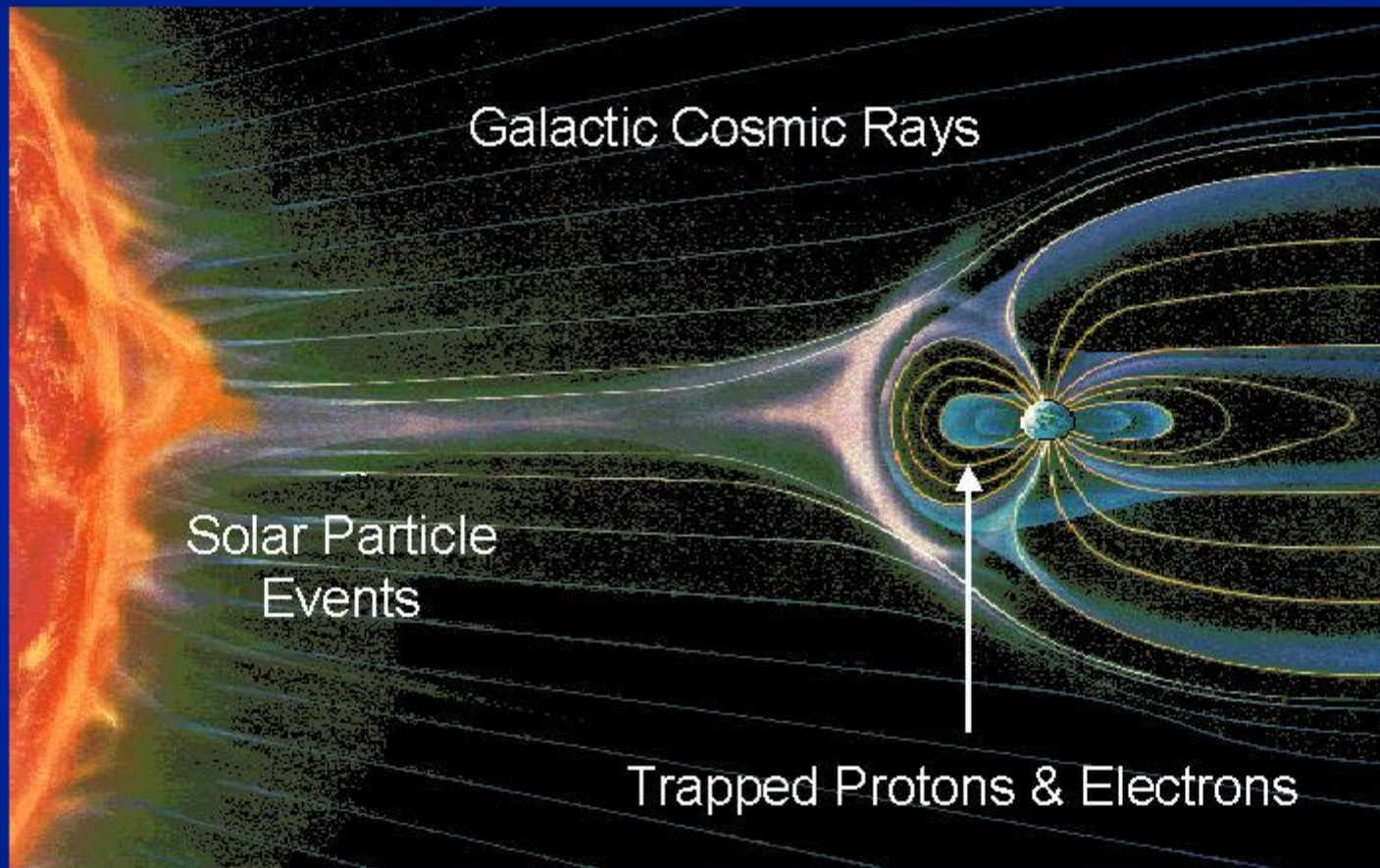
- ♦ Solar cycle is typically 11 years:
  - Solar Maximum (7 years)
  - Solar Minimum (4 years)
- ♦ Common indicators of solar activity:
  - sunspot numbers
  - 10.7 cm radio flux







# *High Energy Radiation Particles*





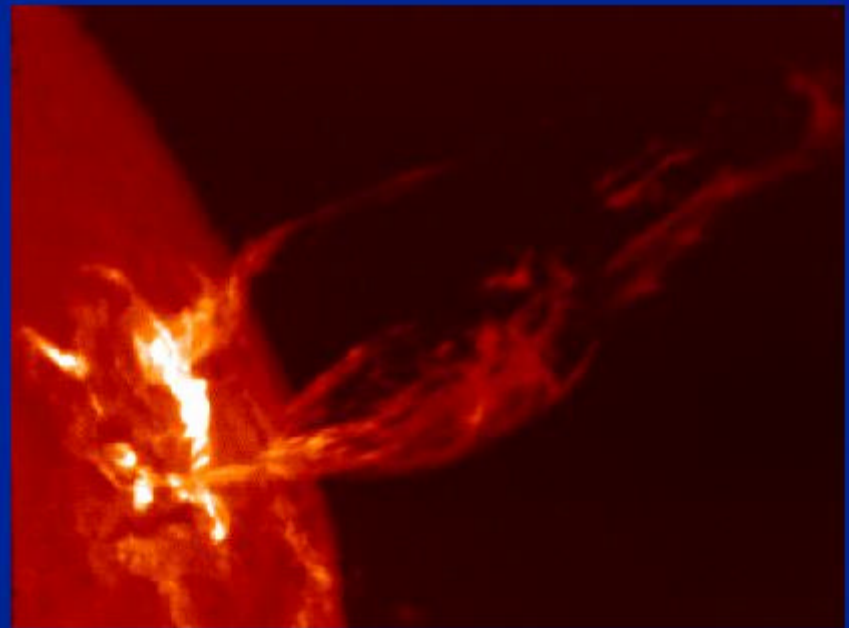
# ***Solar Particle Events***





# ***Solar Particle Event Characteristics***

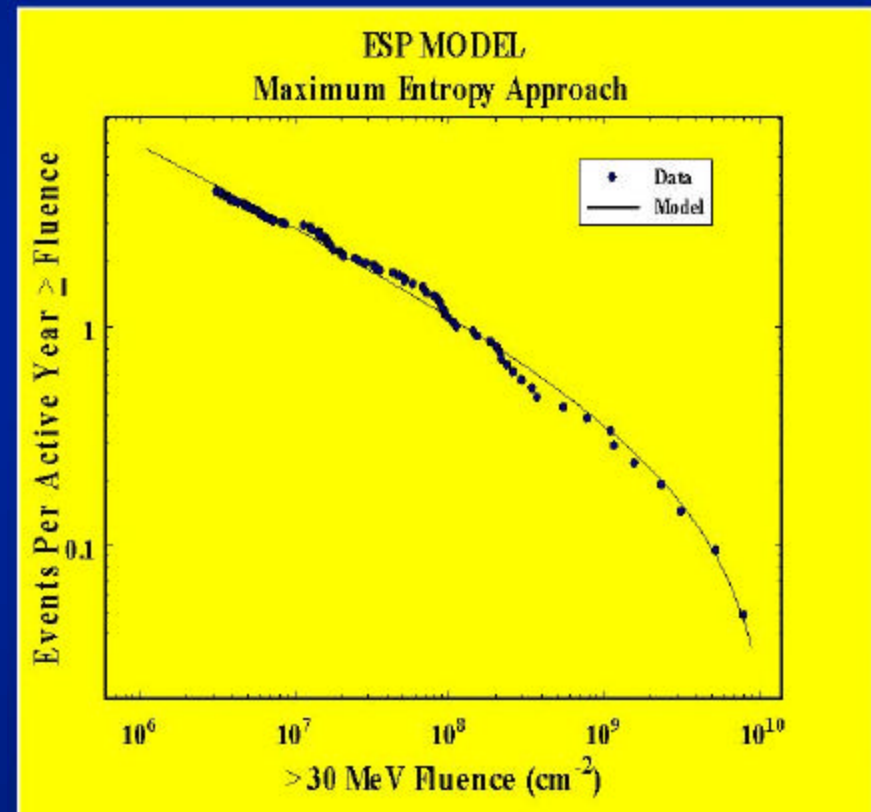
- ◆ Occur randomly in time, more frequently during solar maximum
- ◆ Event sizes span orders of magnitude
- ◆ Radiation consists of protons, heavy ions, electrons, x-rays,...
- ◆ Energies: up to  $\sim$ GeV/nucleon
- ◆ Duration: hours to days
- ◆ Ionizing dose: up to  $\sim$ krad(Si)





# Solar Proton Event Models

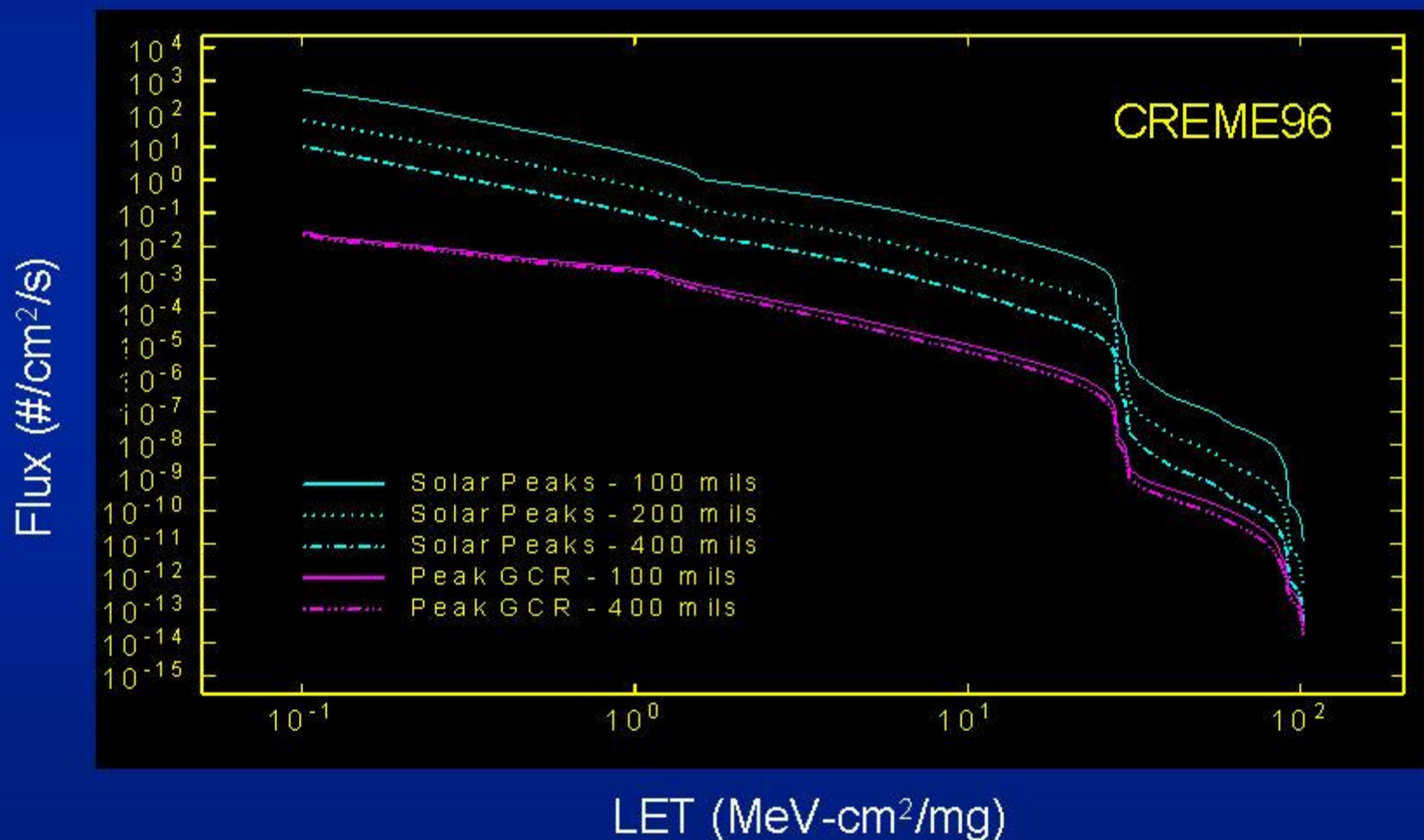
- ◆ Predict proton fluences for given confidence level and mission duration
  - » SOLPRO
  - » JPL91
  - » ESP
- ◆ ESP is most advanced
  - » Based on cycles 20-22
  - » Describes complete range of measured event sizes
  - » Cumulative fluences and worst case events
  - » Upper limit in event size agrees well with historical evidence





# Solar Heavy Ions

Unattenuated by Magnetosphere





# ***Galactic Cosmic Rays***



# ***Galactic Cosmic Ray Ion Characteristics***

- ◆ **Originate beyond our solar system**
  - » **Isotropic distribution**
- ◆ **Composed of all naturally occurring nuclei ranging from protons to uranium**
  - » **87% protons**
  - » **12% alpha particles**
  - » **1% heavier ions**
- ◆ **Highly or completely ionized**
- ◆ **Energies up to at least  $10^{11}$  GeV!**
  - » **Energy spectrum peaks  $\sim 1$  GeV / nucleon**



# ***Galactic Cosmic Ray Solar Cycle Modulation***

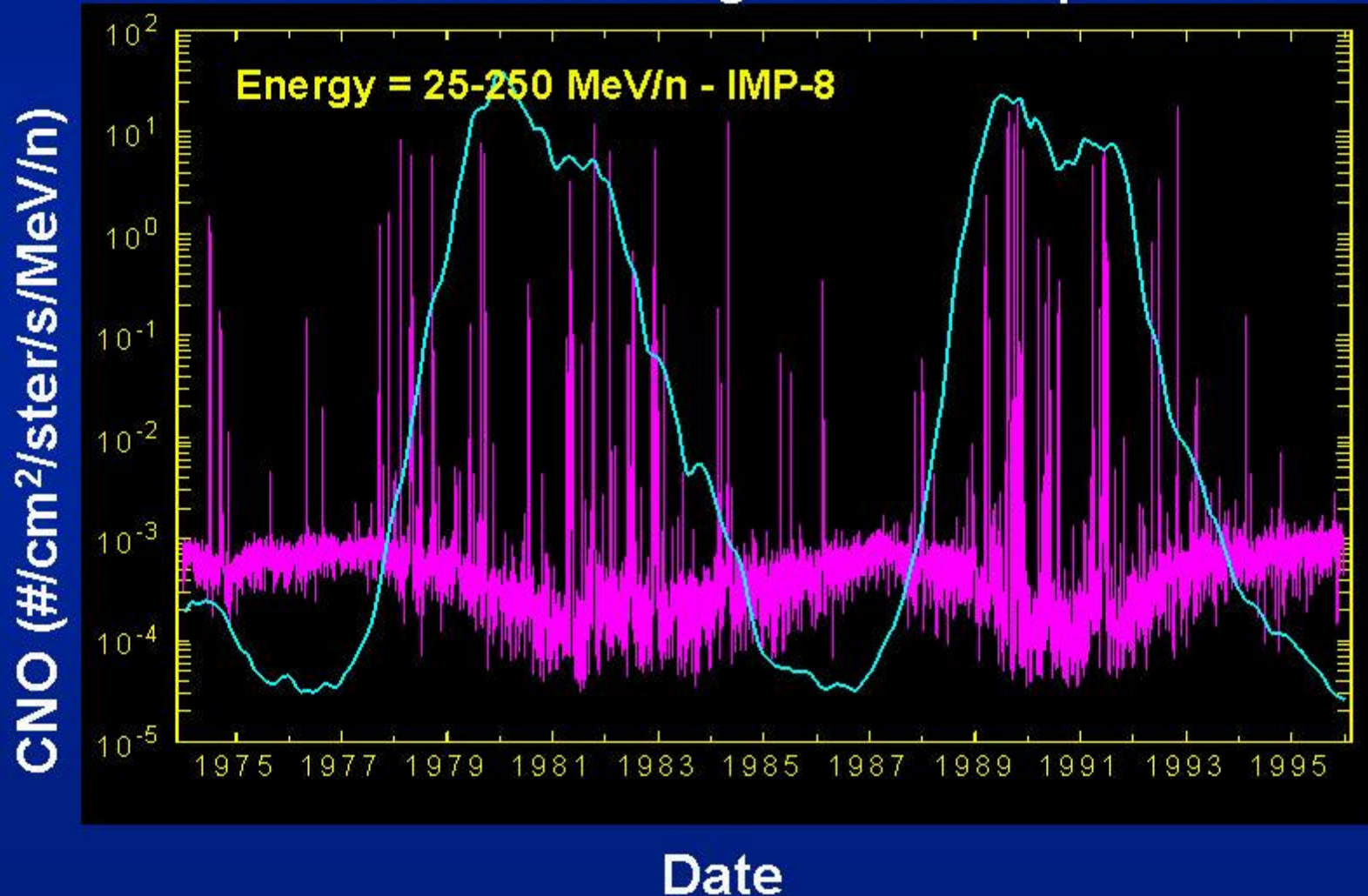
- ◆ **Cyclic variation of ion fluences**
  - » **Lowest fluences during solar maximum**
  - » **Highest fluences during solar minimum**
  - » **Cyclical nature most pronounced at low energies; differences not seen at  $\sim 10$  MeV/nucleon and beyond**
  
- ◆ **Current models – diffusion/convection theory**
  - » **Describe cyclical variation with semi-empirical deceleration potential; interaction with solar wind**
    - **Badhwar and O'Neill**
    - **Nymmik**
    - **Lee and Adams**
    - **Chenette**





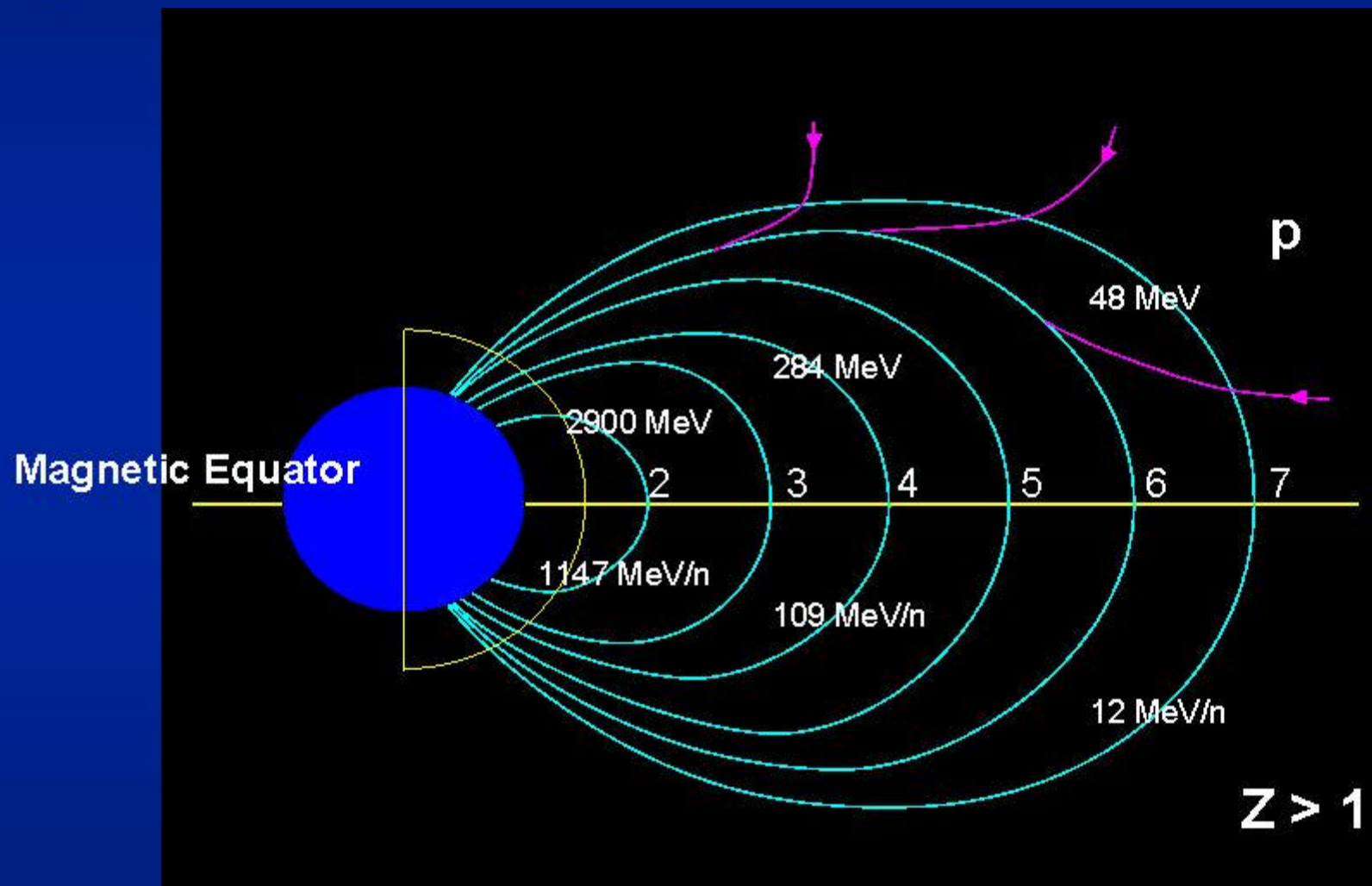
# Heavy Ion Population

CNO - 24 Hour Averaged Mean Exposure Flux





## Energy Required to Penetrate Magnetosphere



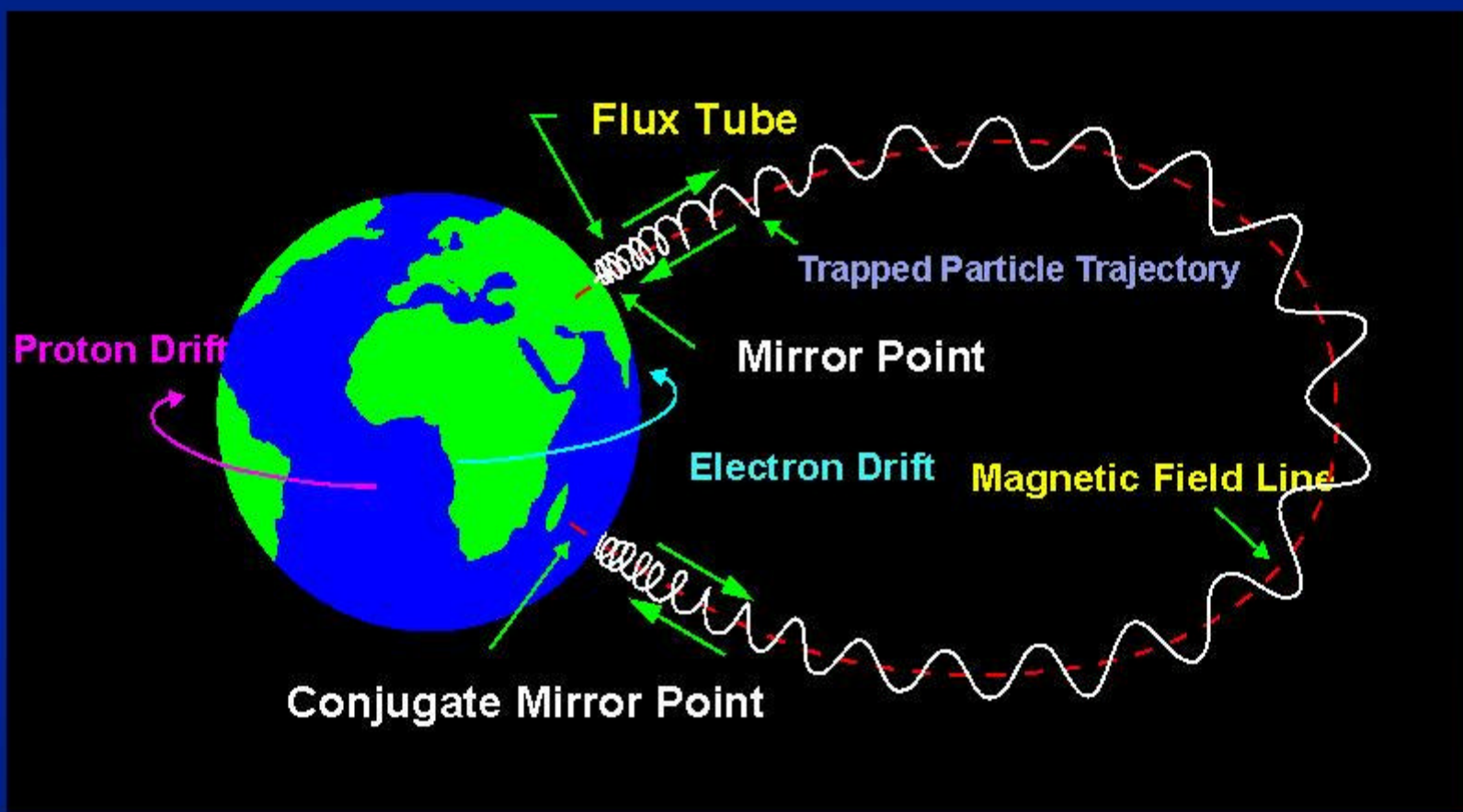
*after Stassinopoulos*



# ***Trapped Particles***



# Trapped Particle Motions



*after Hess*



# ***Trapped Proton Characteristics***

- ◆ **Single trapped proton region**
- ◆ **Proton energies up to ~ 500 MeV**
- ◆ **Low Altitudes (< 1000 km)**
  - » **Exposure mainly due to South Atlantic Anomaly**
  - » **Average exposure gradually decreases during solar maximum by factor of ~ 2.**
- ◆ **Fluxes in medium earth orbits generally quite severe.**



# *Trapped Electron Characteristics*

## ◆ Inner Belt:

- »  $1.0 < L < 2.8$
- » Energies  $< 4.5$  MeV

- ◆ Average fluxes gradually increase during solar maximum by factor of  $\sim 2$

## ◆ Outer Belt:

- »  $2.8 < L < 12$
- » Energies  $< 7$  (?) MeV

## ◆ Fluxes Dynamic

- » Greater variability with increasing altitude
- » Correlation with solar rotation period

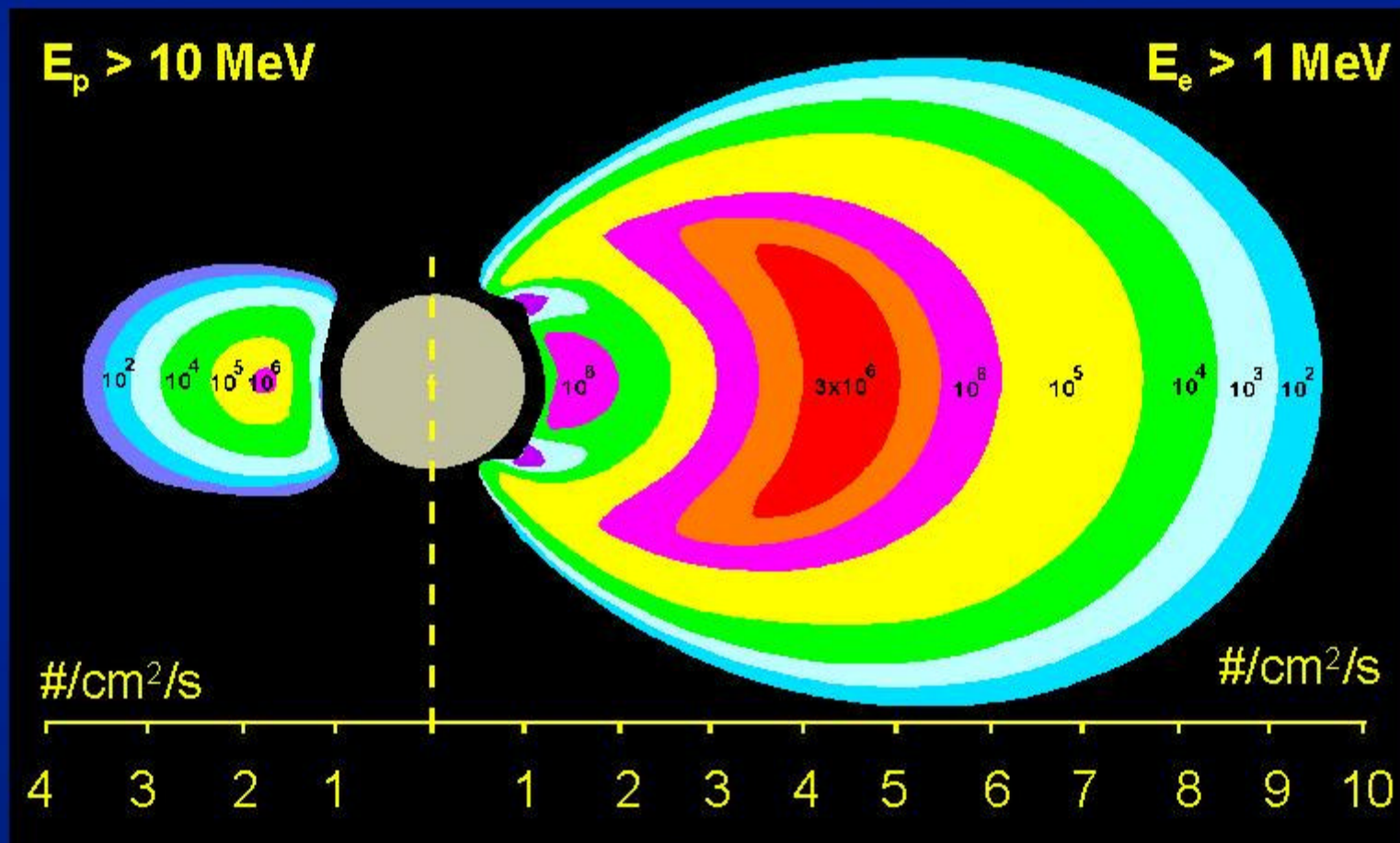




# Proton & Electron Intensities

AP-8 Model

AE-8 Model



L-Shell

NASA/GSFC



## ***Some Recent Trapped Particle Models***

- ◆ **Low Altitude Trapped Proton Model  
(Huston and Pfitzer)**
  - » Accounts for variation with solar cycle activity
- ◆ **CRRESPRO (AFRL)**
  - » Quiet and active proton environment for  
 $1.15 < L < 5$
- ◆ **CRRESELE (AFRL)**
  - » Trapped electrons for different levels of  
magnetic activity for  $2.5 < L < 6.5$



## ***Trapped Particles - Jupiter***

- ◆ **Jupiter has largest magnetosphere in solar system.**
- ◆ **Very severe trapped radiation environment measured by Galileo spacecraft**
  - » **Protons**
  - » **Oxygen**
  - » **Sulphur**
- ◆ **Modeling effort by JPL ongoing.**



# Summary

## ◆ Space radiations covered:

- » Solar particle events
- » Galactic cosmic rays
- » Trapped particles

## ◆ Recommended sources:

- » MSFC SEE Program – <http://see.msfc.nasa.gov>
- » SPENVIS – [www.spenvis.oma.be/spenvis/](http://www.spenvis.oma.be/spenvis/)
- » CREME96 – <http://crsp3.nrl.navy.mil/creme96/>
- » Langley technical publications – <http://techreports.larc.nasa.gov/ltrs/>